Parameterization of Nonlocal Mixing in the Marine Boundary Layer: A Study Combining Measurements and Large-Eddy Simulation

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LONG-TERM GOAL

The long-range goal of this research is to improve understanding of small-scale mixing processes in the atmospheric boundary layer and to incorporate the effects of these processes in mesoscale models.

OBJECTIVES

The objectives of this project are to use a combination of observations, large-eddy simulation model results, and mesoscale model simulations to examine the formation and behavior of the marine boundary layer under low-wind conditions. Our focus is on understanding how stable boundary layers form when winds travel from warm water or land surfaces over colder water. Our main objective is to improve parameterizations of mixing processes for mesoscale models by investigating new approaches for modeling turbulent fluxes in stratified boundary layers.

APPROACH

The central hypothesis of this effort is that improvements in existing parameterizations of turbulent processes require a physical basis and that this basis may be gained through analysis of LES results and boundary layer observations. These model experiments will focus on four main topics driven in part by the CBLAST field experiments and by needed improvements in boundary layer parameterizations:

- Comparison of modeled turbulence with aircraft observations
- Comparison of the LES structure with standard parameterizations
- Analysis of decoupled boundary layer formation
- Development of a marine boundary layer cloud model for studying the effects of SST on cloud systems

Models used in the study include the NRL Coupled Ocean Atmosphere Model Prediction System (COAMPS) and LES model described in Skyllingstad (2003).

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WORK COMPLETED

Work during the final year of this project focused on publishing results from simulations of MBL evolution over SST fronts and expanding the LES model to include cloud and precipitation processes. In addition, a radiative transfer parameterization was implemented for examining stratus clouds where cloud top cooling can have a strong influence on cloud behaviour.

RESULTS

Predicting fog and low cloud formation in coastal waters has long been a major challenge for marine forecasters. Much of the research on coastal stratus has centered on established cloud systems, for example, modeling existing stratus in waters off of California (e.g. Stevens et al. 2005). Very little research has been conducted on the formation of stratus clouds and fog, which is the main emphasis here.

Our hypothesis is that a stable atmosphere over a cooler ocean will under the correct conditions develop fog/stratus when subsidence is minimal and surface winds are moderate. The atmosphere is continuously cooling from infrared radiational loss to space. Consequently, as the atmosphere cools from above and evaporates moisture from the sea surface, conditions conducive to cloud formation will eventually develop. Cooling of the MBL is also produced by movement of air from warm sea-surface temperature over cold sea-surface temperature, as simulated in Skyllingstad, et al. 2007. To study these types of scenarios, the LES model has been expanded to include a microphysics parameterization taken from Thompson et al. (2004) and is currently being used to examine shallow convection over the Gulf Stream.

A shallow convection example is presented in Figure 1, demonstrating the detailed cloud variations produced by the model. Preliminary simulations of stratus clouds based on initial conditions and forcing from Stevens et al. (2005) show good agreement with observed stratus for steady-state conditions. Future modifications to the LES model will include testing of an improved moisture bulk parameterization developed by L. Mahrt. Moisture flux parameterization in the current version of the model is based on the COARE algorithm, which was developed primarily from tropical data. Mahrt has found that midlatitude moisture flux can be significantly smaller than the COARE value because of the reduced importance of the virtual temperature effect on buoyancy.

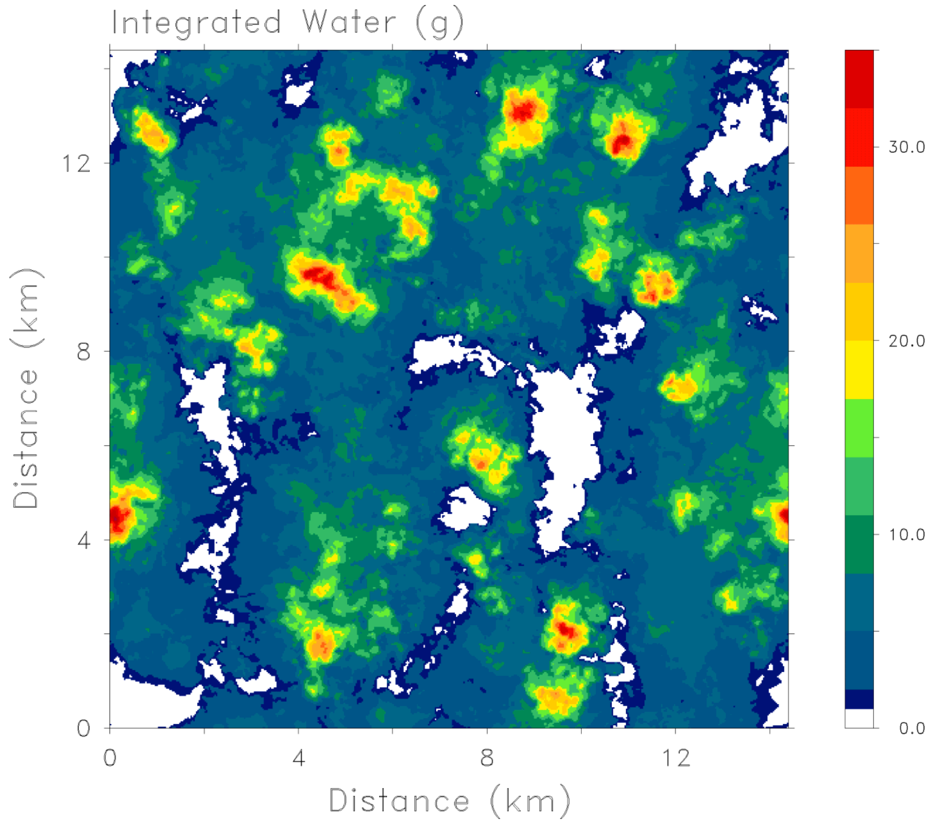

Figure 1. Integrated cloud water content (g) for a simulation of shallow convection over the Gulf Stream.

Future simulations as part of our coupled modeling project will focus on the formation of stratus and fog in response to upwelling and flow around orography. One common feature of cloud fields along the Oregon and California coasts is variations in cloud thickness forced by flow changes around points and capes. Often, a clear slot will appear down wind from a point in the area of the flow where the MBL is thin. Interaction between the terrain forcing and SST-forced decoupling presumably lead to this thinning, but the dynamics of this process are not completely understood.

TRANSITIONS

The results from this work may have important consequences for mesocale modeling in the coastal zone where SST can vary on small scales. Results from this work will be communicated to Navy researchers (S. Wang, J. Pullen) who are actively involved in mesoscale modeling activities.

RELATED PROJECTS

This work complements efforts to model the coupled ocean atmosphere system (ONR project, Skyllingstad and Samelson). Both of these projects utilize coastal atmospheric models that will benefit from improved understanding of the marine boundary layer.

REFERENCES

Stevens, et al., 2005. Evaluation of large-eddy simulations via observations of nocturnal marine stratocumulus. *Mon. Wea. Rev*., 133, 1443-1462.

Thompson, G., R. M. Rasmussen, and K. Manning, 2004. Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis. *Mon. Wea. Rev*., 132, 519-542.

PUBLICATIONS

Skyllingstad, E. D., D. Vickers, L. Mahrt, R. Samelson, 2007. Effects of mesoscale sea-surface temperature fronts on the marine boundary layer. *Boundary-Layer Meteorol*., 123, 219-237.